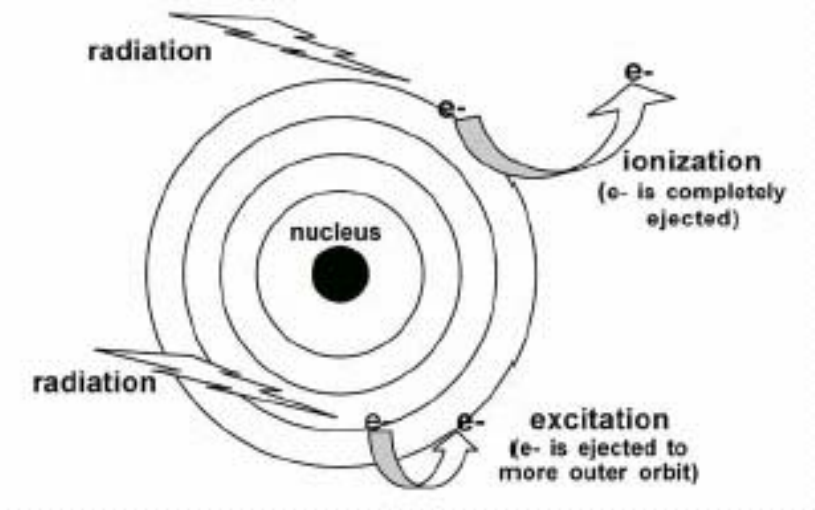
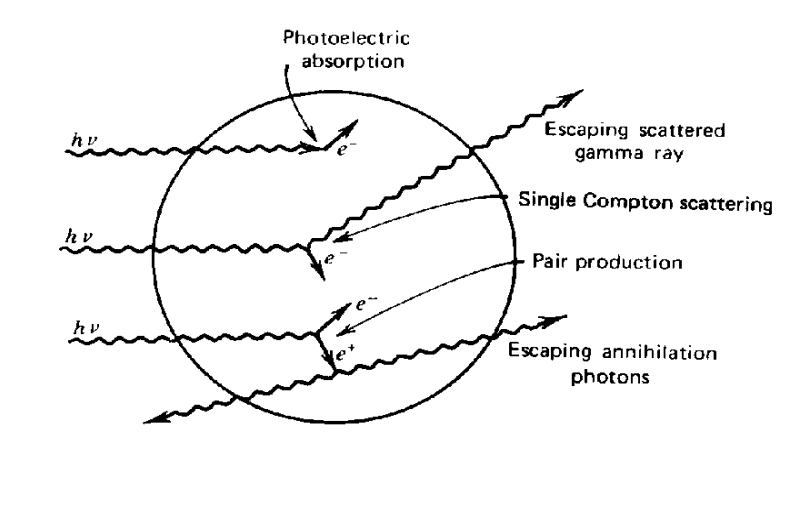
An Introduction to Ionizing radiation interaction with matter



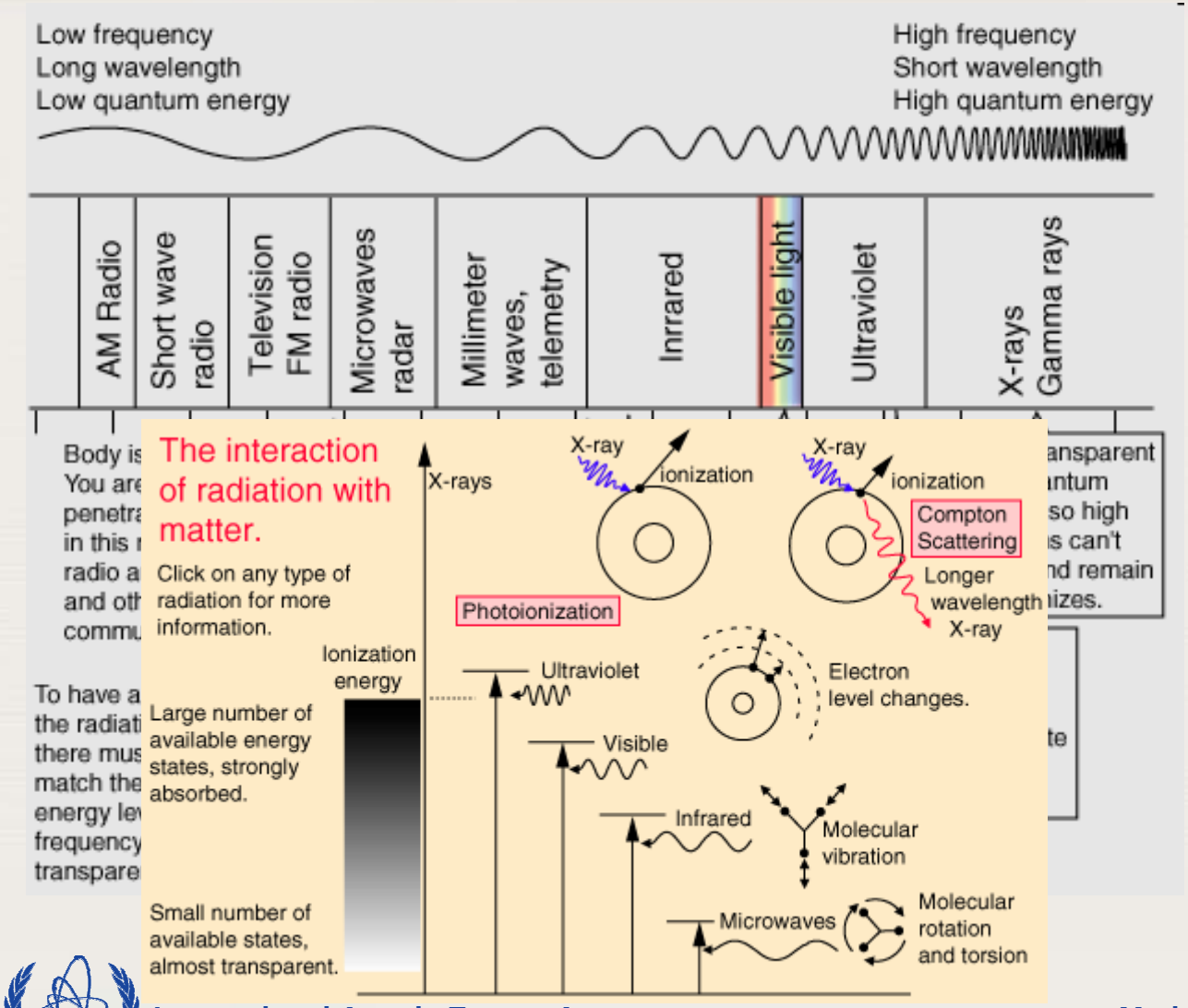


Mats Eriksson

Ionizing radiation interactions

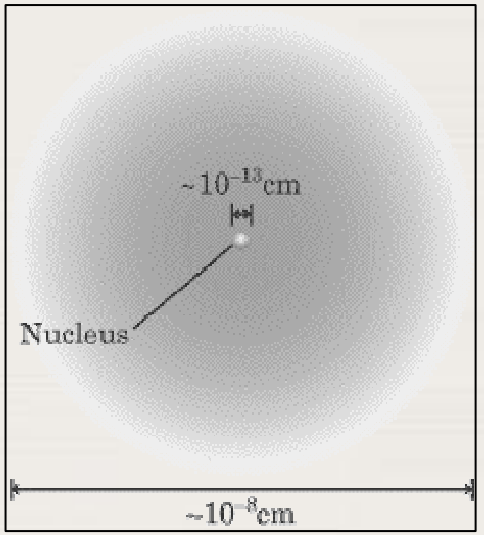
- Photon interactions
  - Photoelectric effect
  - Compton scattering
  - Pair production
  - Coherent scattering
  - Photonuclear interaction
- Photon attenuation
  - Linear attenuation
  - Mass attenuation
- Charged particle interactions
  - Elastic scattering
  - In elastic scattering
  - Breamsstrahlung
- Summary with examples
  - Detectors
  - Gamma spectrometry
  - XRF analysis
  - Dosimetry

Energy and Matter scales



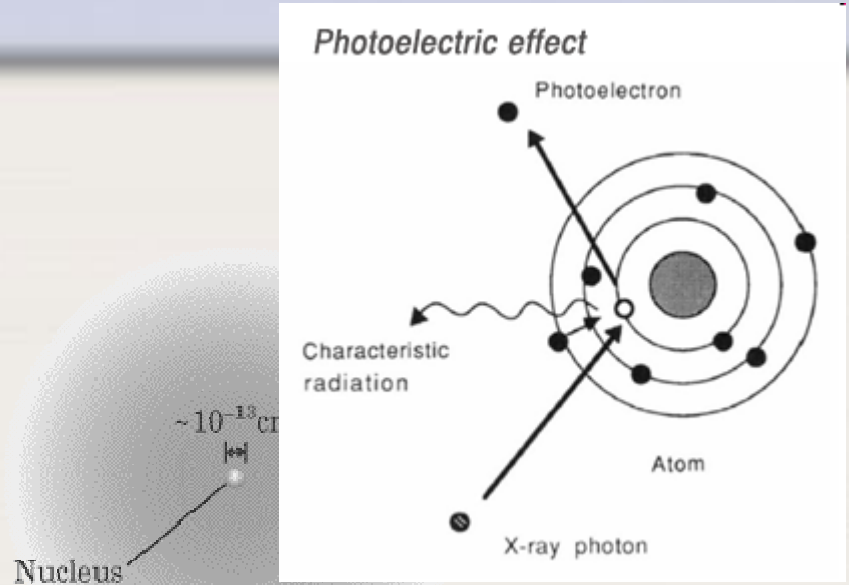
Energy of a photon, E_{ph}

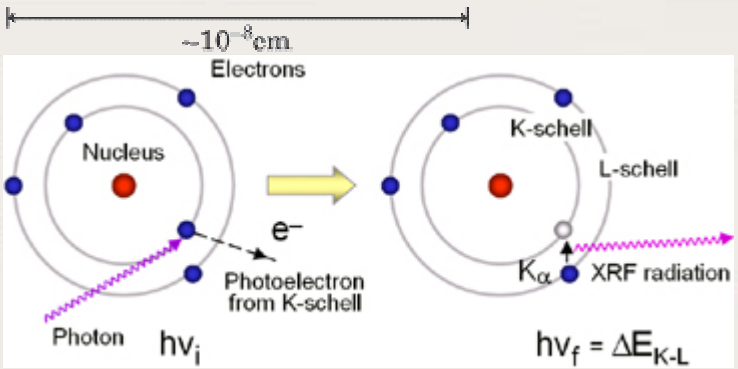
$E_{ph} = h\upsilon$



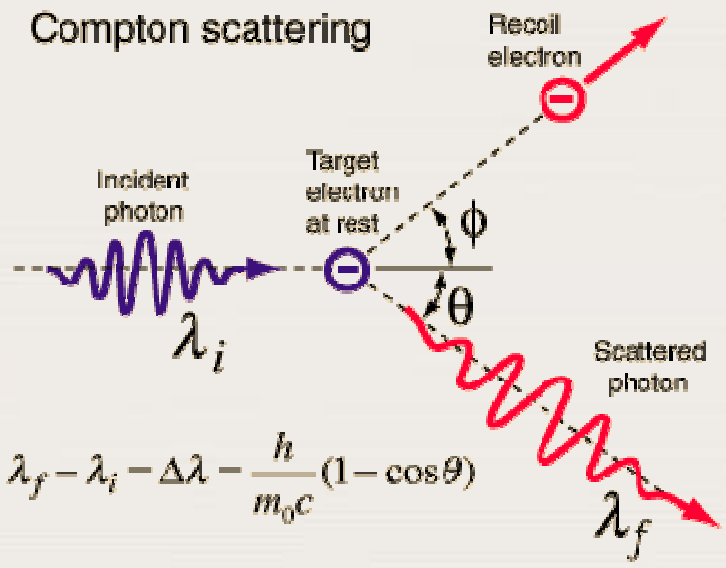
Photon interaction; Photoelectric effect

- A photon interacts with a hard bounded atomic electron, most often with K or L shell electrons
- E_{ph} higher than the binding energy of the electrons
- The kinetic energy of the photoelectron, $E_{phe}=E_{ph}-E_{bind}$





Photon interaction; Compton scattering



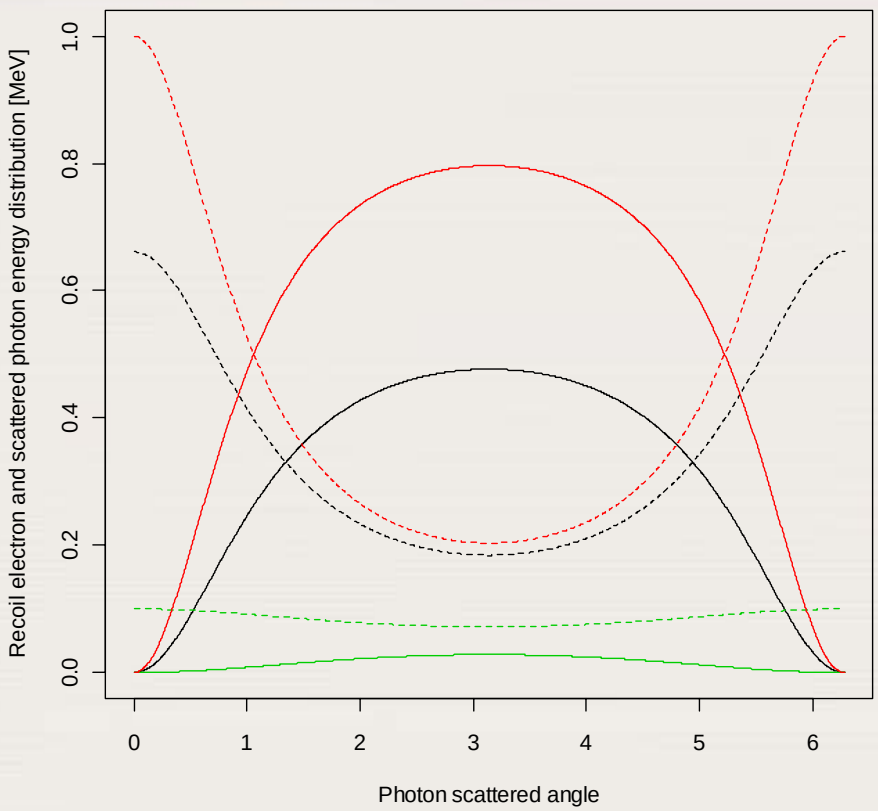
$$\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_0 c}(1-\cos\theta)$$

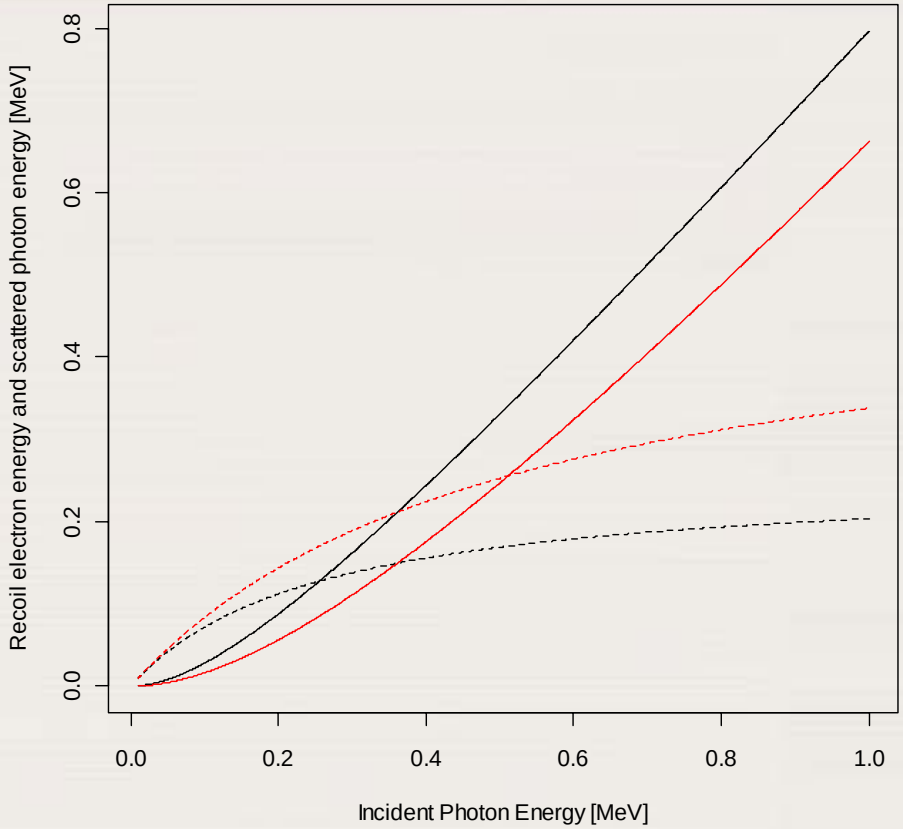
$$\frac{1}{h\nu_f} - \frac{1}{h\nu_i} = \frac{1}{m_e c^2}(1-\cos\theta)$$

- The incident photon interacts with a "free" atomic electron. From the interaction points a recoil electron and a photon (called scattered photon) is leaving sharing the energy of the incident photon.

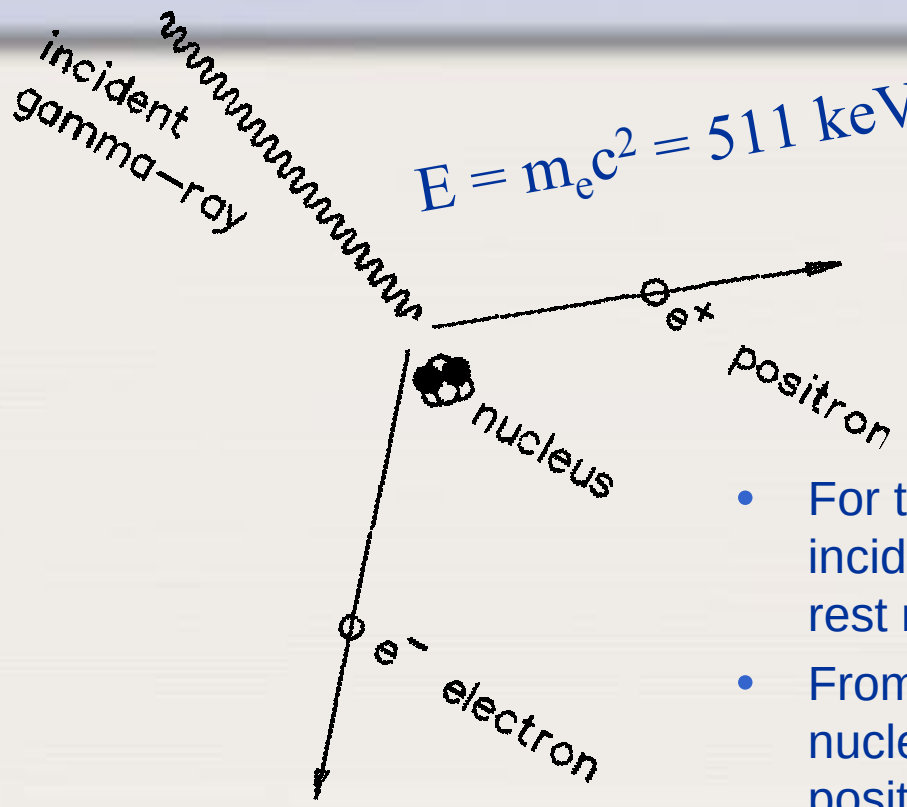
- The interaction is called Compton scattering after Arthur Compton who was the first to measure photon-electron scattering in 1922.

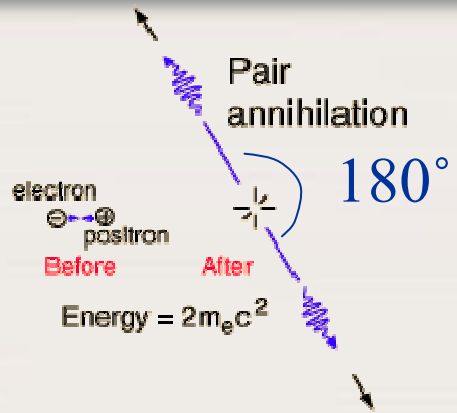
Compton scattering,

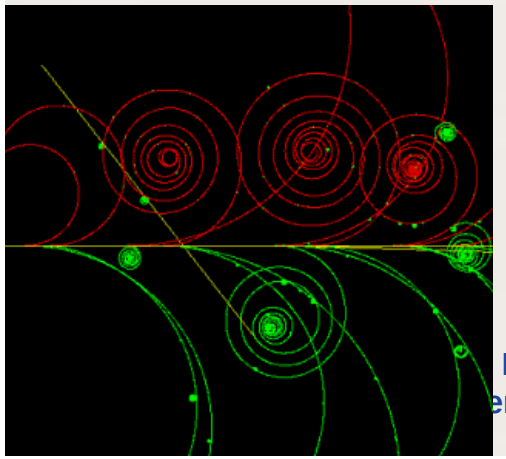




Photon interaction; Pair production



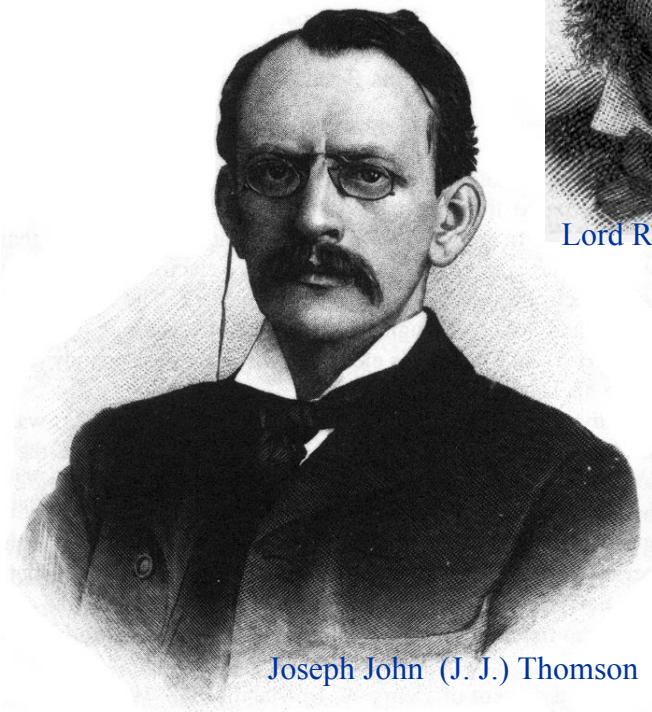




- For this photon interaction it requires that the incident photon have two times the electron rest mass, i.e. an energy above 1022 keV
- From the interaction point (close to the nucleus of an atom) the electron and a positron pair is leaving (pair production)
- For photon energies far above this threshold, pair production becomes the dominant mode for the interaction photons with matter.

Coherent scattering
(Rayleigh, Thomson, Classical or Elastic scattering)

Lord Rayleigh (John William Strutt)

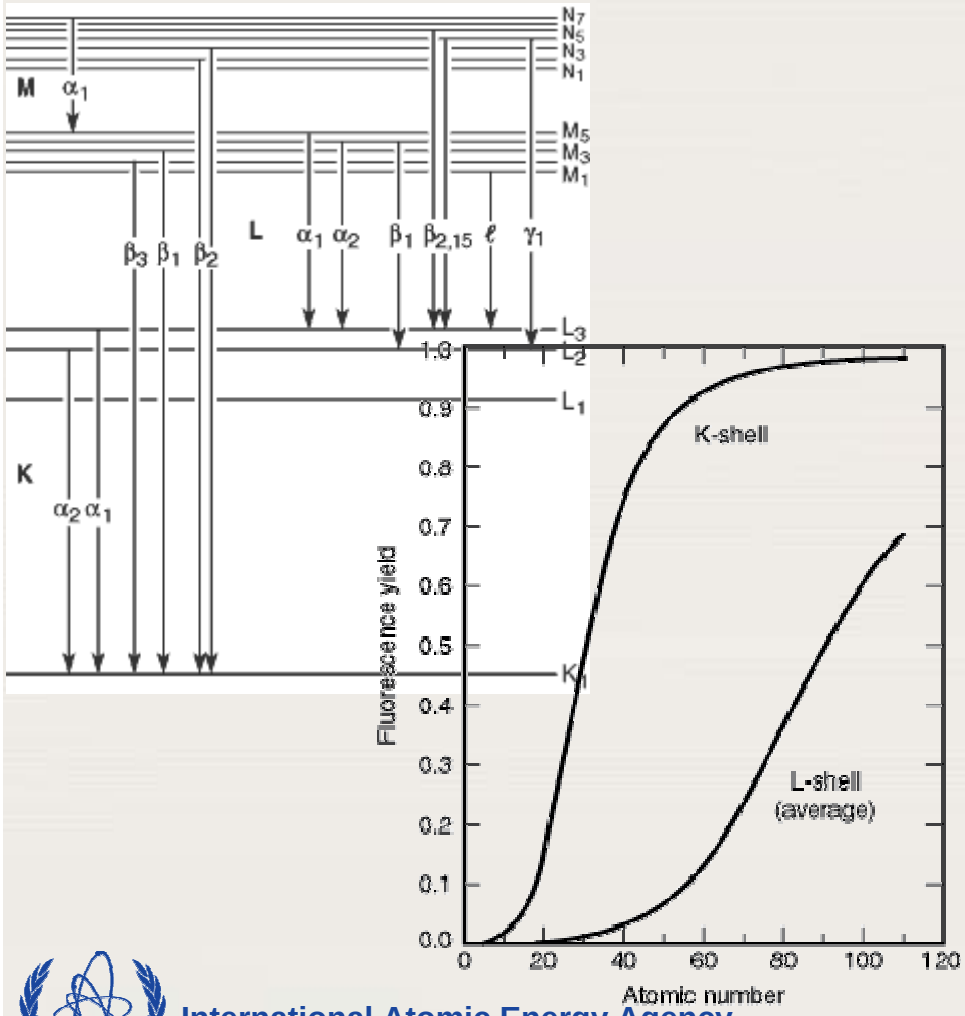


Joseph John (J. J.) Thomson

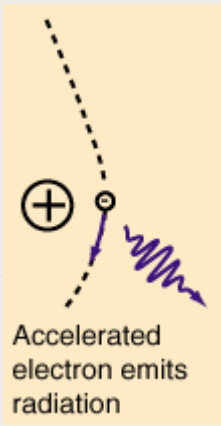
- A Photon (wave package) interacts with an atomic electron that sets in an oscillation.
- The oscillating electron radiates a photon with the same energy as the incoming photon, however with a possible change of direction,
- Minimum scattering into the right angle to the incoming photon.
- Mostly an interaction in high atomic number material combined with a low photon energy.
- Not an important interaction in gamma ray spectrometry, in XRF the interaction is considered.

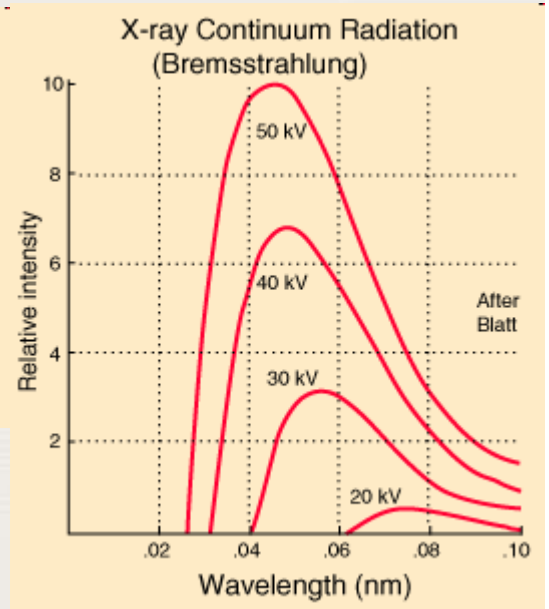
X ray radiation production

Characteristic X-ray

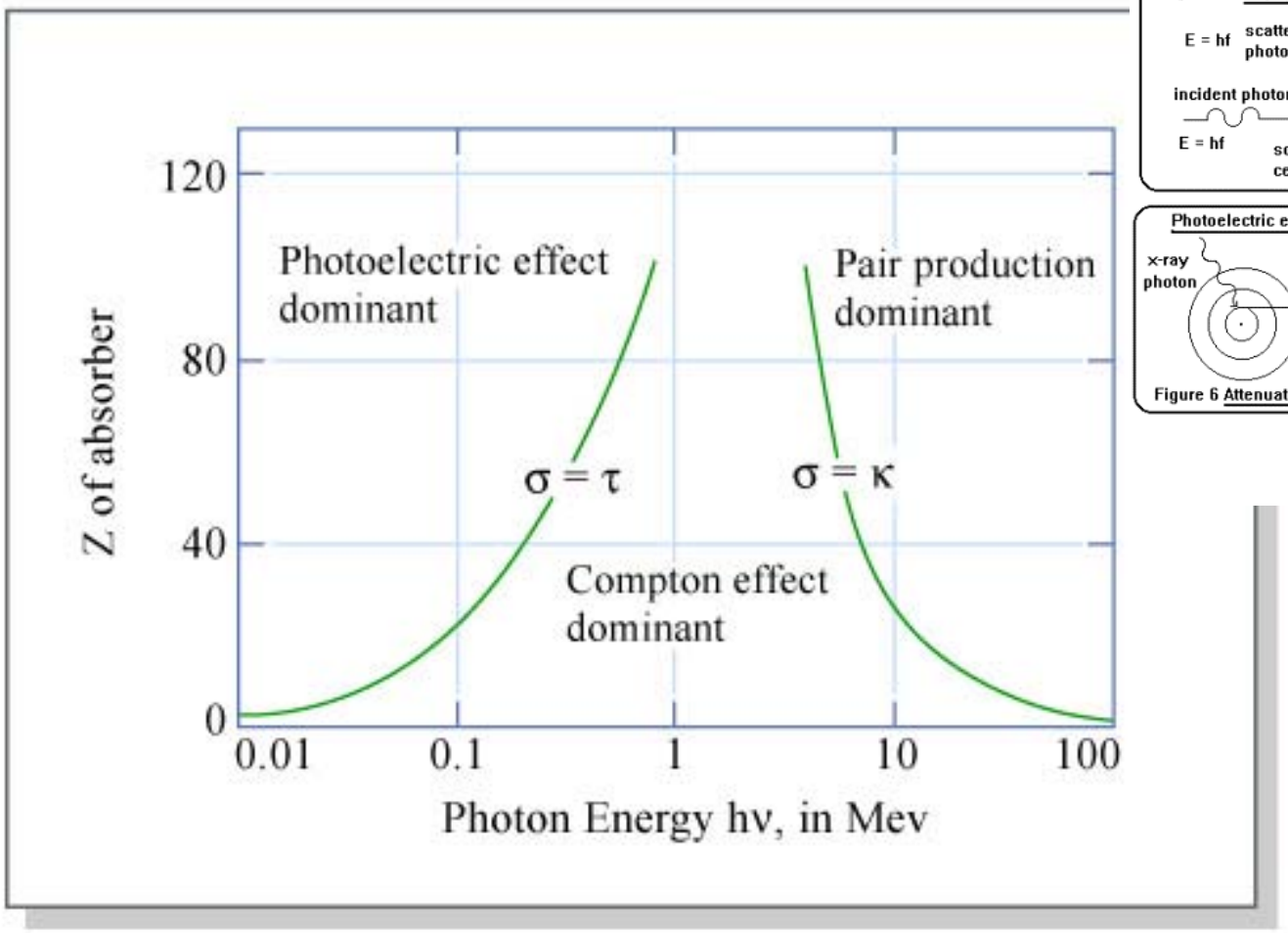


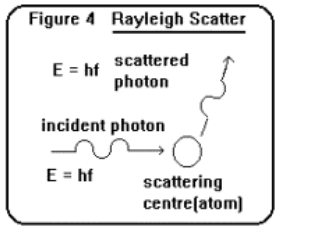
Breamsstrahlung;
only by charged particles

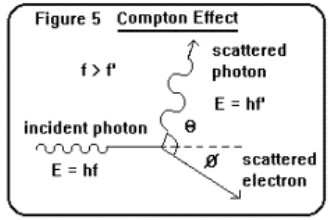


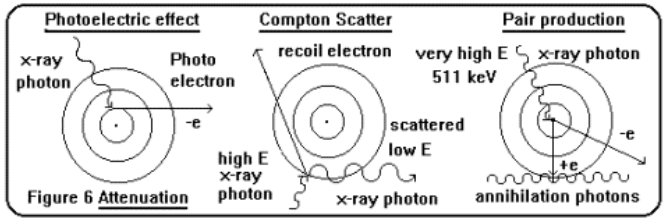


The “Window” of Photon interactions



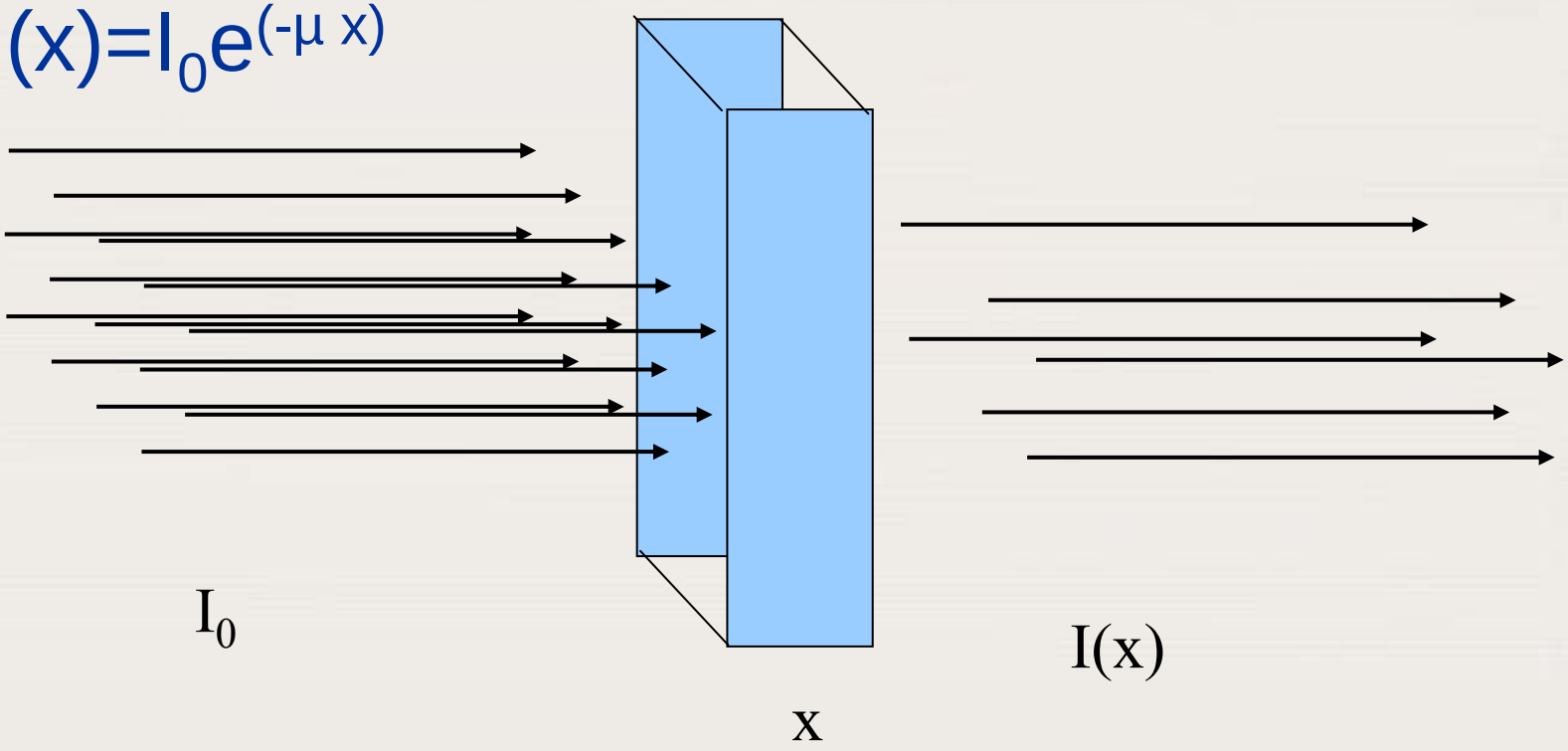






Absorption, primary photons losses due to interaction

- Cross-section
- The attenuation is energy dependent
- $I(x)=I_0 e^{(-\mu x)}$

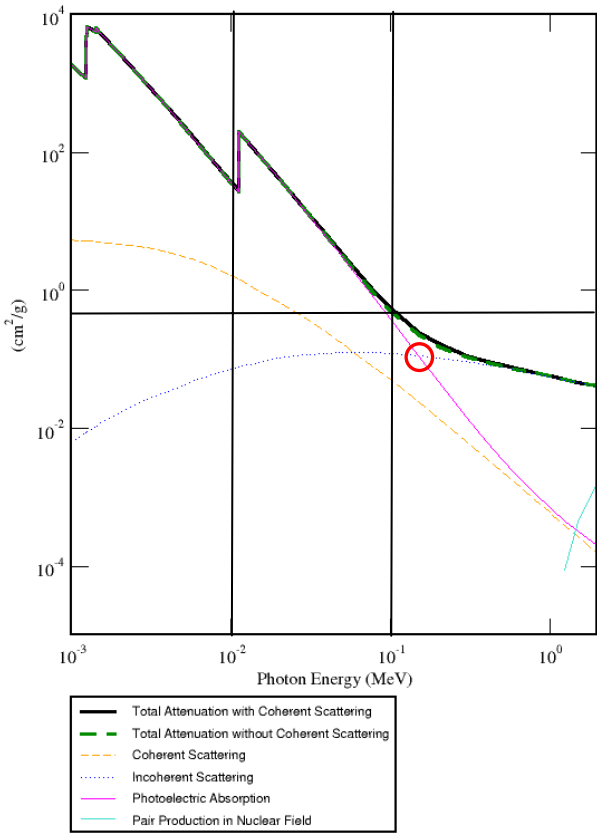


Absorption

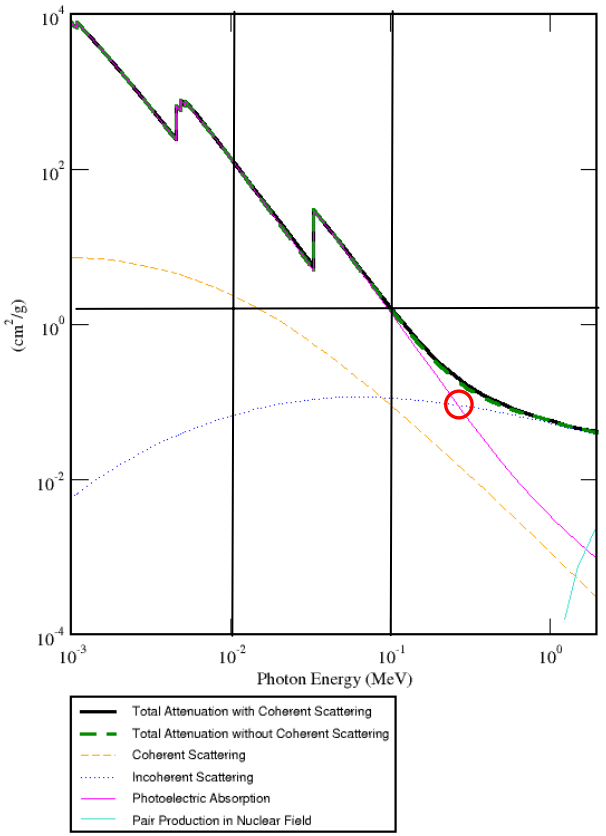
- Energy dependency on the absorption and material (eg. 10, 100 keV) (Ge, NaI, Pb)
- μ; includes attenuation due to all photon interactions

Data from XCOM

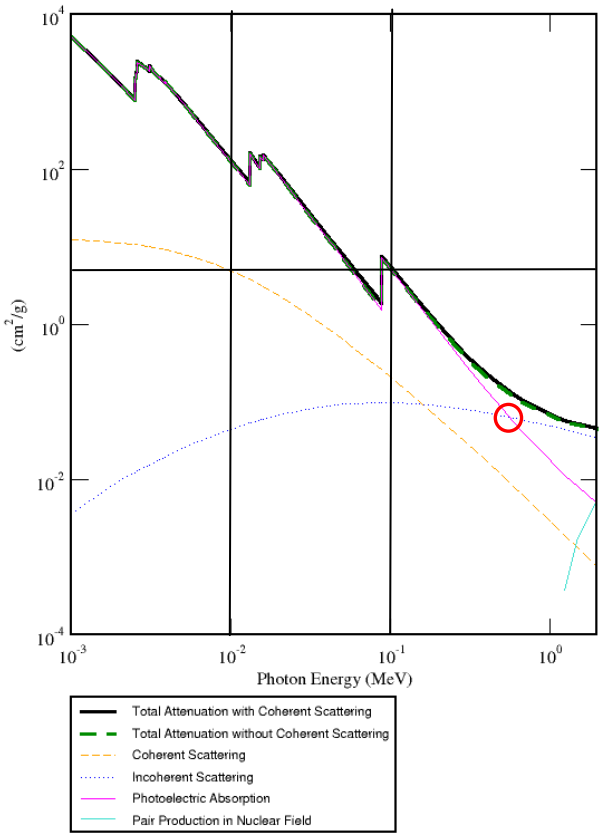
Germanium



NaI



Lead

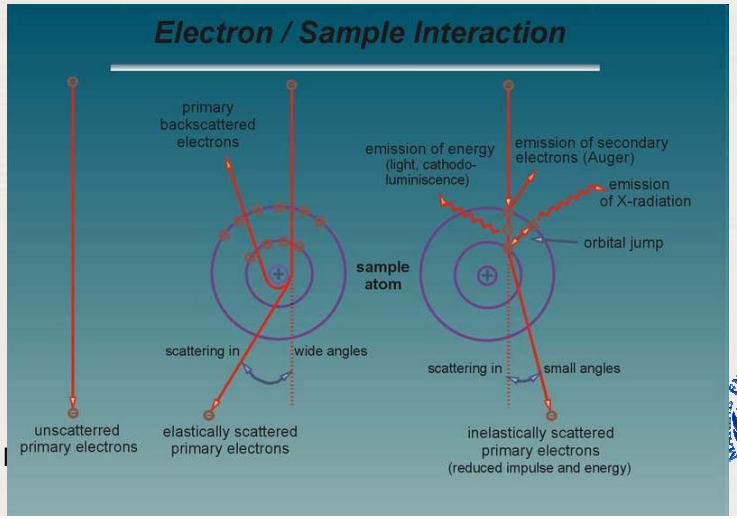


Absorption coefficients

- The linear absorption coefficient is μ_l (cm–1) is related to the transmitted photon intensity of an energy through a material with a thickness of x:
  - $I(x)=I_0 e^{(-\mu_l x)}$
- The mass absorption coefficient μ (cm2/g) is related to the transmitted intensity through a material of density ρ (g/cm3) and thickness x by:
  - $I(x) = I_0\, e^{-\mu \rho x}$; $\mu=\mu_l \rho$
- For a compound material, the mass absorption coefficient is obtained from the sum of the absorption coefficients of the constituent elements, weight by the elemental atom ratio in the material.
- XCOM data base at NIST can be used.

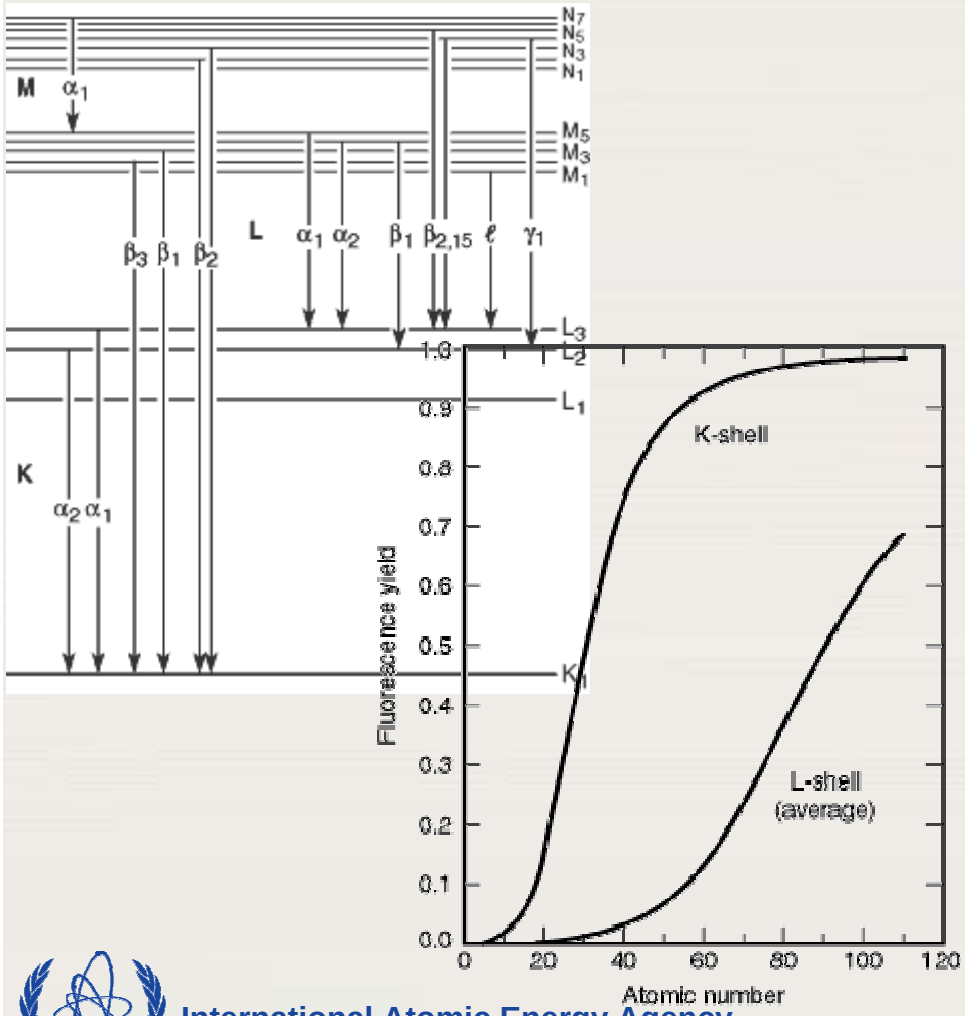
Charged particle interactions

- Charged particles interacts due to their electric charge with the atomic electrons (nucleus interactions rare)
- Betas, interacting via columbian forces
- lose energy in a continuous way, while photons lose energy by discrete interactions in specific places.

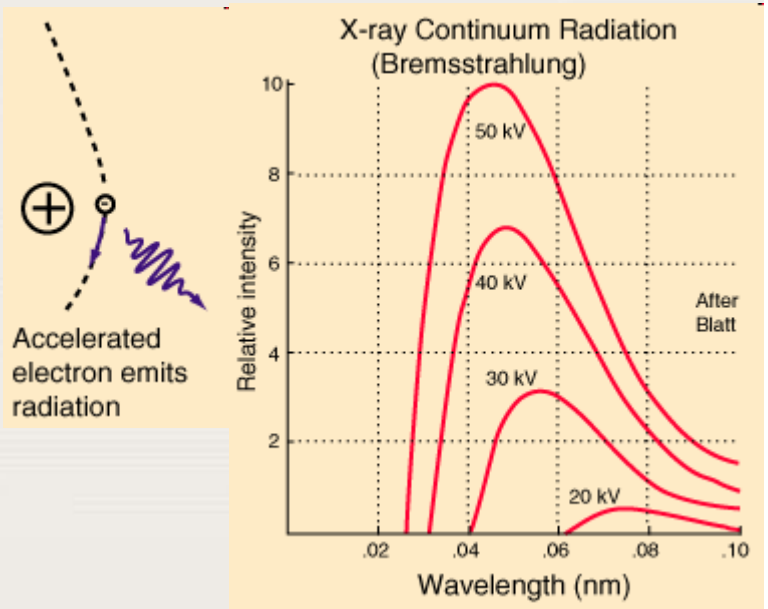


X ray radiation production

Characteristic X-ray



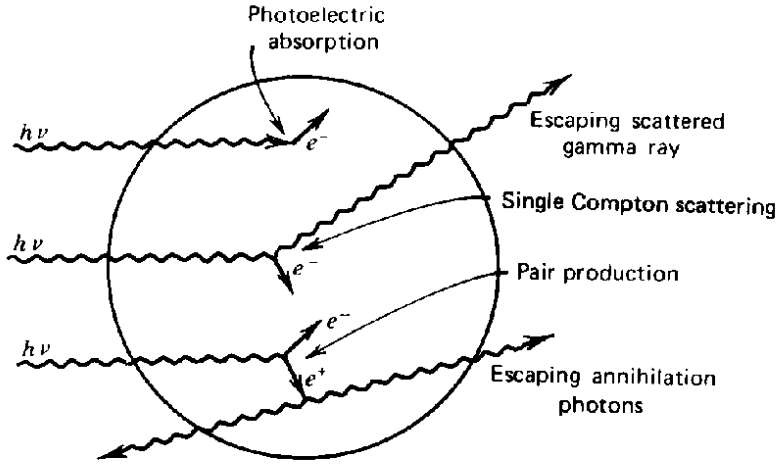
Breamsstrahlung;
only by charge particles



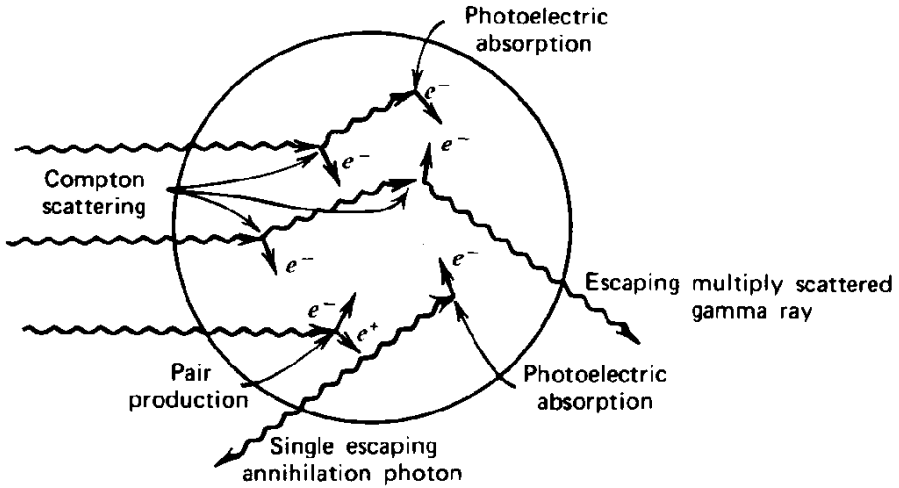
Some examples of Applications

- Detectors
- Gamma spectrometry
- XRF analysis
- Dosimetry

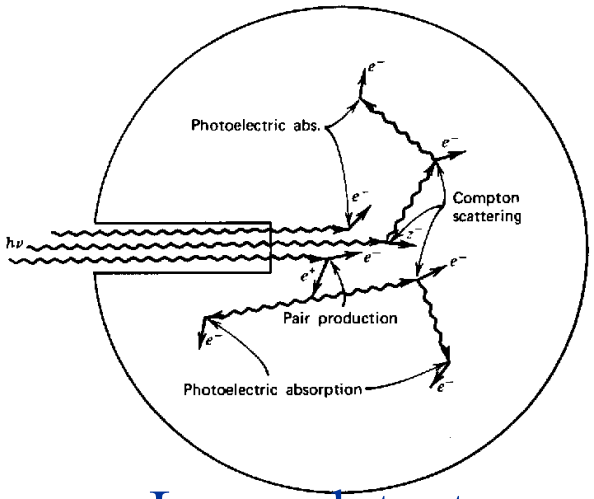
Interaction in Detectors



Small detector



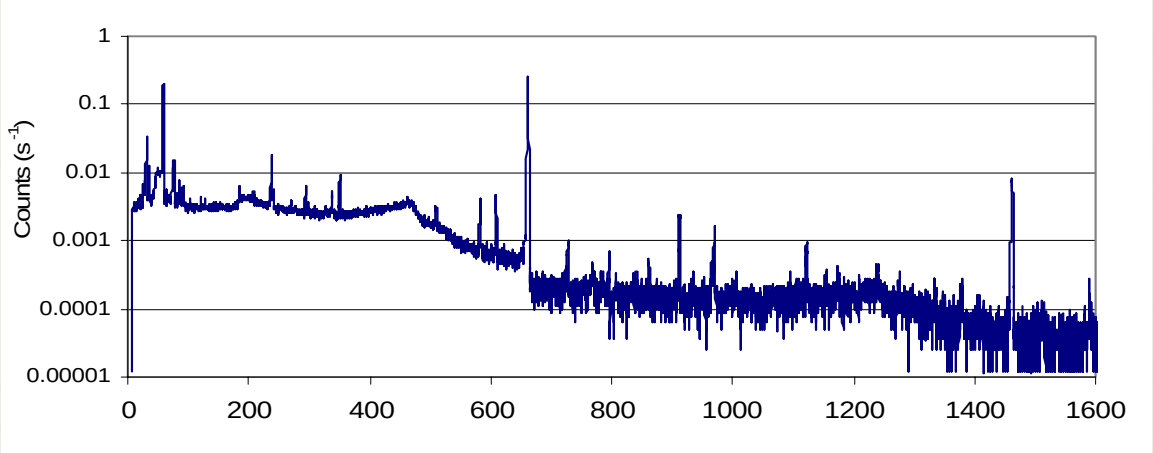
Medium sized detector

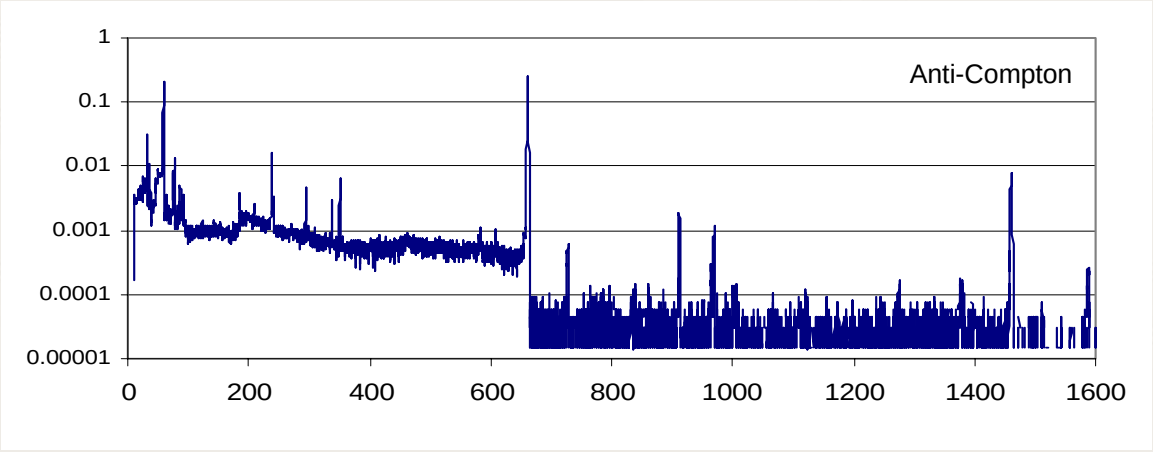


Large detector

Gamma spectrometry

Gamma-spectrometry measurements of IAEA-135 Irish Sea sediment sample





Some XRF set-up

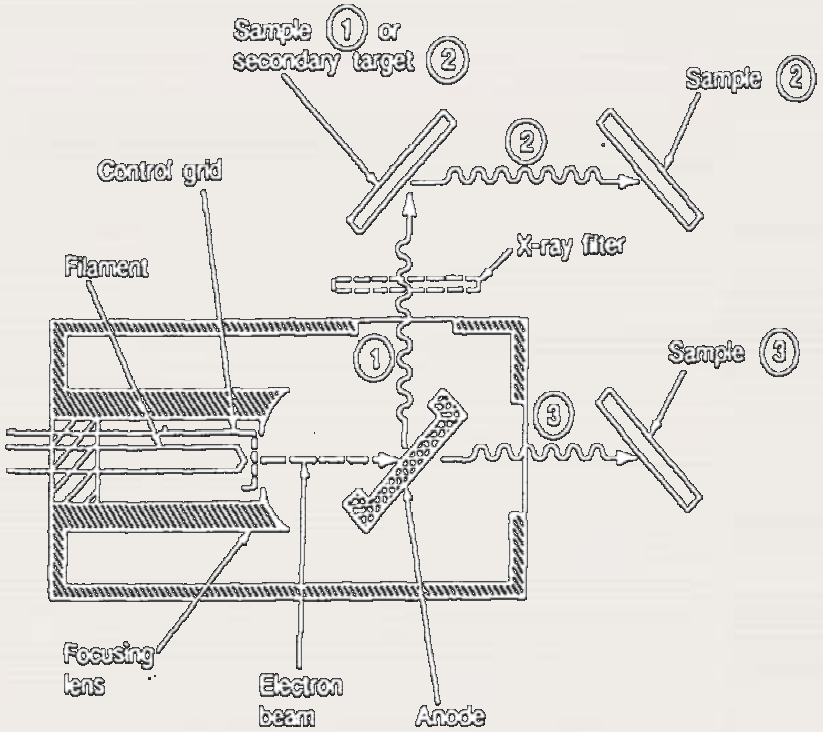
Typical excitation geometries

for an X-ray tube:

1) direct excitation

2) secondary target excitation

3) transmission geometry



Thank you for your time!

- Acknowledgement to the web-pages where I have “borrowed” all the very nice illustrations!

- Questions?